# Cryogenic Polarization Chopper for Millimeter and Sub-Millimeter Waves

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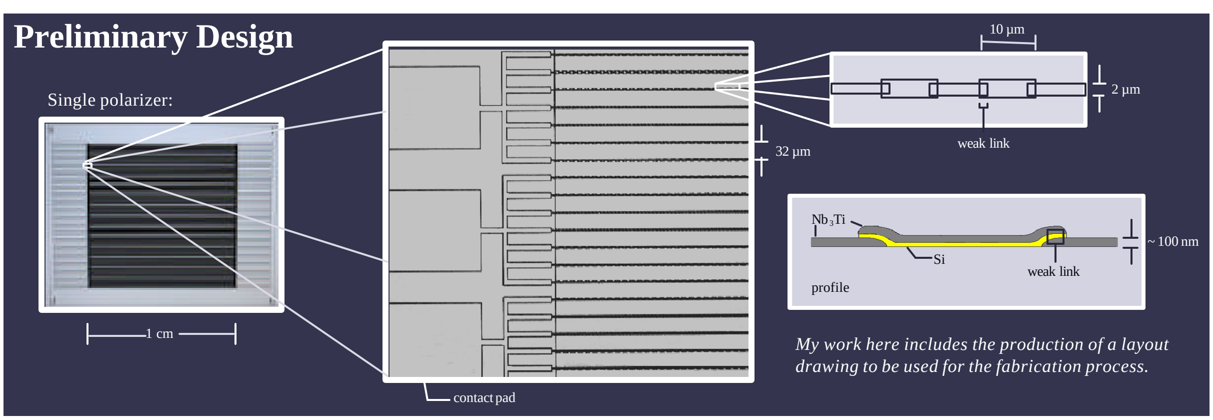
**Abstract**: The polarization of the Cosmic Microwave Background (CMB) is perhaps the only photon diagnostic of the pre-inflationary Universe. Studying the polarization exhibited by CMB anisotropies can provide information on primordial gravitational waves and on the epoch of a secondary reionization, as well as further knowledge of primordial temperature anisotropies. We are developing optical components to modulate polarized millimeter and sub-millimeter wavelengths in the hopes of detecting these weak polarization signals from the CMB. Unlike conventional optical modulators, these optical components have no moving parts and are compatible with cryogenic detectors such as those for NASA's planned Inflation Probe mission.

## Description of the Chopper:

- Two linear polarizers with orthogonal transmission axes
- Cryogenic chopper with no moving parts achievable with "weak links"
    - Weak links sufficient but possibly not required; however, we believe that weak links result in lower power dissipation than other solutions
- Superconductive $Nb_3Ti$: Critical temperature ($T_C$) ~ 10K
- Each polarizer will switch between two states (on/off)
- "On" and "off" states correspond to superconducting and normal states
    - Device will operate below $T_C$
    - Normal state achieved by applying a current $I > I_C$ (Silsbee effect)
- Differential signal between transmitted polarizations can be obtained



## Behavior of Weak Links:

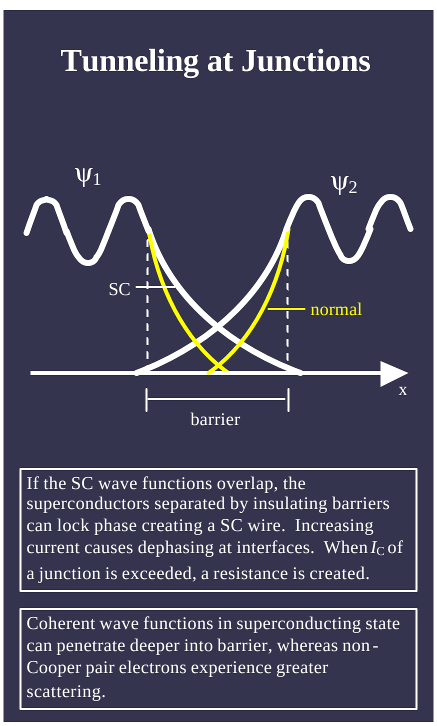
*Superconductor-insulator-superconductor (SIS) junction during superconducting mode:*

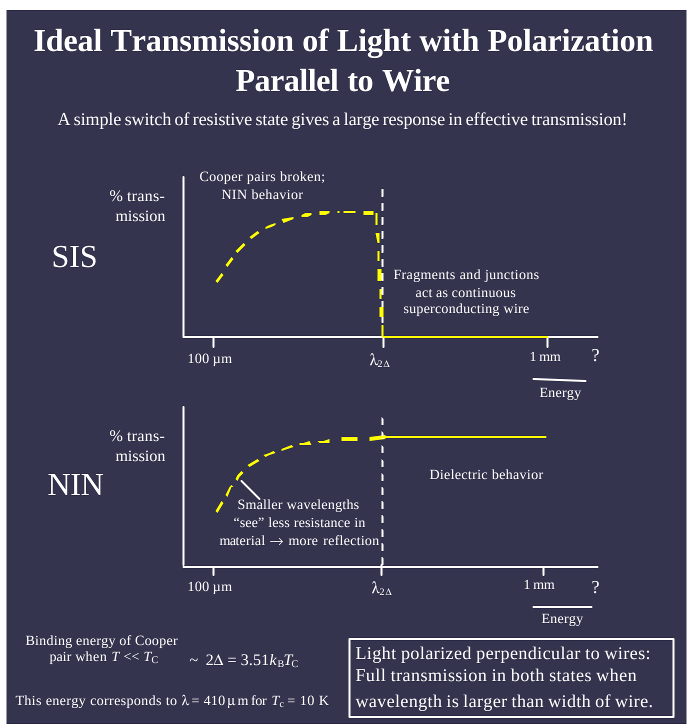
- Thickness of insulating barrier must be less than coherence length, $x_0$, of Cooper pair
- DC Josephson effect: Supercurrent of pairs via quantum-mechanical tunneling
- Junction has minimal effect on superconductivity
- Material behaves as perfect conductor when $E_{\text{photon}} = hc/? < 2\Delta$
  $\rightarrow$ high reflection of incident photons

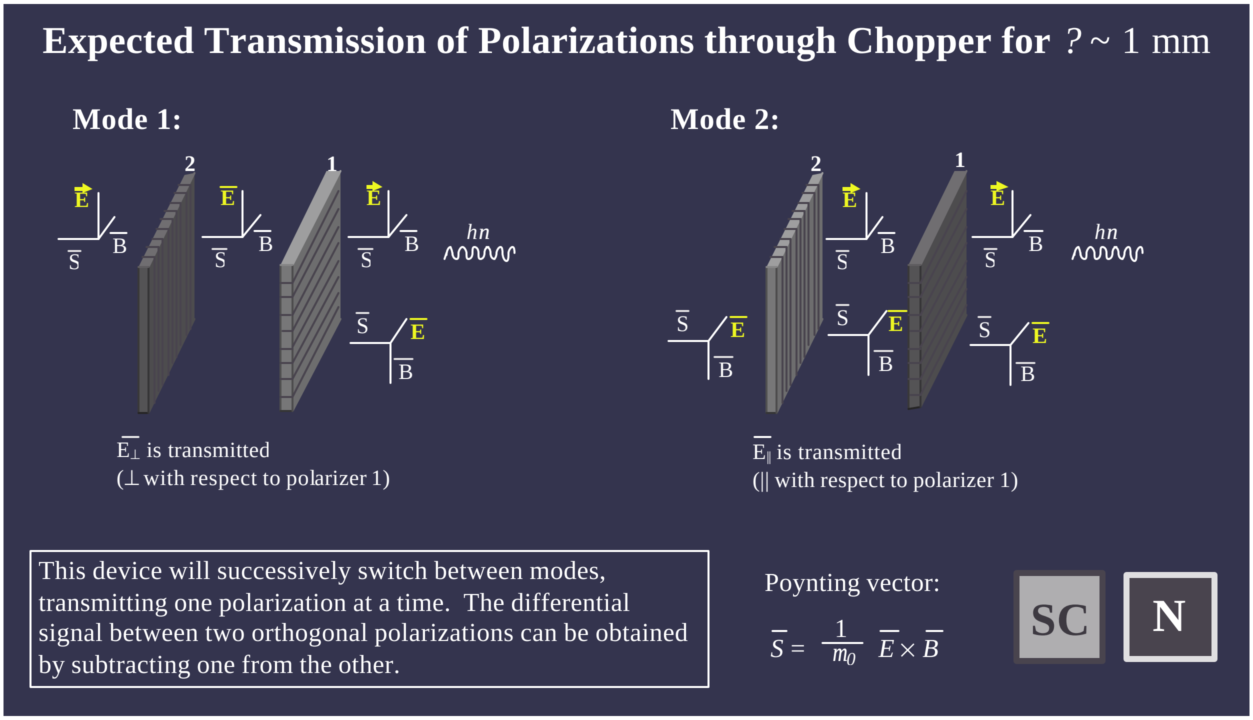
*Normal-insulator-normal (NIN) junction during normal mode:*

- Lower tunneling probability; voltage drop across junction
- Junction creates large resistance between respective wire fragments
  - No coupling of radiation when $L_{\text{fragment}} << ?_{\text{photon}}$
  - Material behaves as dielectric
    $\rightarrow$ high transmission of incident photons

The weak links allow tuning of $I_C$ and $R_{\text{eff}}$ of the wire with the junction thickness, resulting in greater engineering capabilities. They also help to reduce Joule heating in the system which is more compatible with cryogenic detectors.

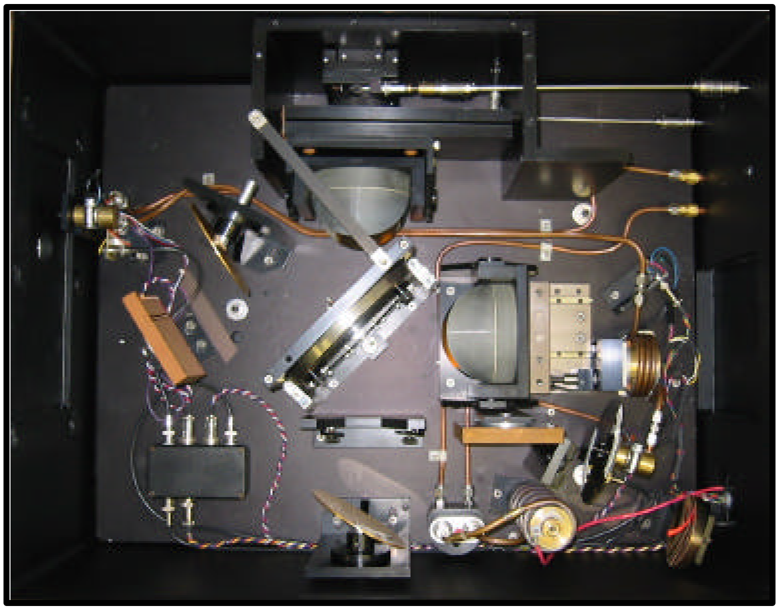




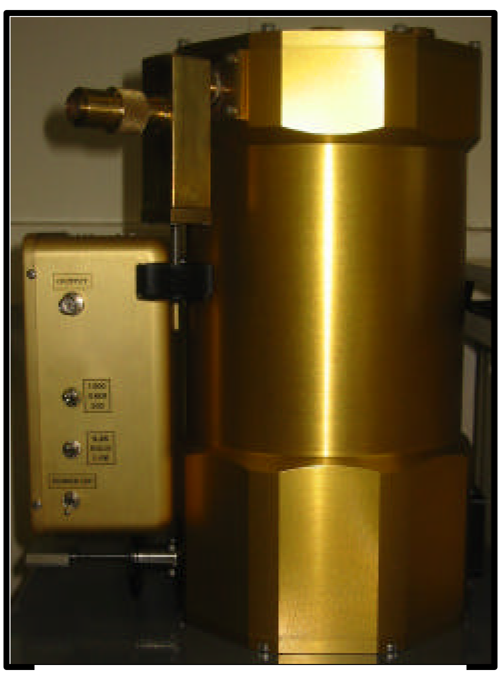

## Short-term Goals:

- Determine the optimal film thickness, *d*
  - The requirements are a high enough $T_C$ ( > 4.2 K) and a high resistivity, *r*, when normal
  - Smaller thicknesses yield larger resistances: $d \sim r^{-1}$
  - $T_C$ can be suppressed with film thickness
  - Find *r* (*d*,*T*) and $T_C$ (*d*) down to 4K using four-terminal measurement technique
- Determine the optimal weak link thickness, *a*
  - Compromise: Need thin barrier for greater SIS junction tunneling, though this necessitates a larger $I_C$
  - Measure $I_C$ (*a*)
- Specifications are now complete; chopper is ready for fabrication
- Test transmission of light in normal and superconducting states
  - Fourier Transform Spectrometer (FTS), bolometer, and dewar
  - Test at various temperatures from 4K → 1K

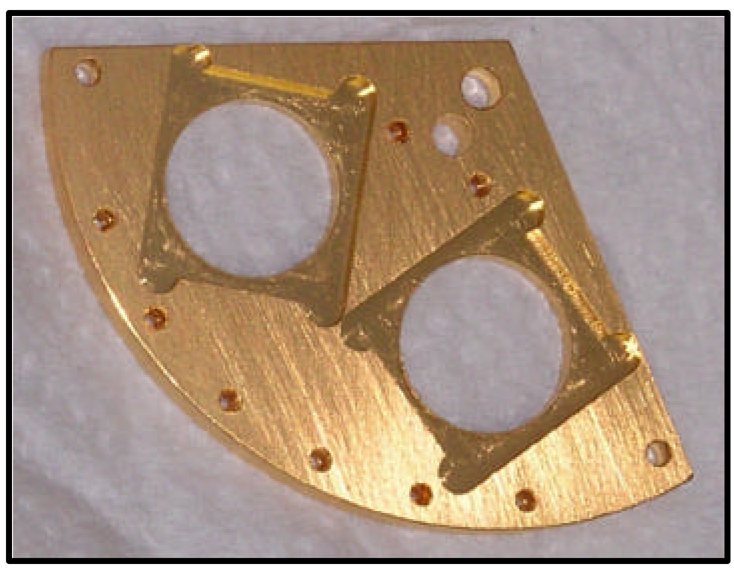


**FTS**

**DT-470 Thermometer**



**Dewar**



I designed the chopper holder that will be placed in the dewar for future transmission testing.

## Current Results:

| ***d*** **[nm]** | ***T*$_c$ [K]** | ***R*$_{sq}$ [W/? ] *T* ~ 298 K** | ***R*$_{sq}$ [W/? ] *T* ~ 10 K** | *x* **[nm]** |
|---|---|---|---|---|
| 47.6 | 7.50 | 31.5 | 28.5 | 12.5 |
| 58.6 | 9.18 | 41.2 | 31.4 | 9.67 |
| 95.23 | 8.22 | 14.2 | 11.4 | 13.3 |
| 127 | 9.90 | 12.1 | 8.55 | 12.1 |

Effective coherence length: $x$ = ?$x_0 l_{mfp}$?$^{½}$
$l_{mfp}$: Mean free path computed by Drude model